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Market competition, lobbying influence and environmental externalities

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ABSTRACT

In this paper, we contribute to the debate regarding the relationship between lobbying and environmental regulation by explicitly taking into account the role of market competition. We analyse how the number of firms affects both the effectiveness of lobbying in fighting environmental regulation and the individual incentive for firms to switch to green technology. To explore this issue, we present a Cournot oligopoly where firms can choose between abating the environmental externality or lobbying the government to hold a loose regulation. We investigate two alternative government's political objectives. In the first, government aims to only minimise the externality, while in the second, it also cares about the consumers surplus. We find that, in both cases, the higher the number of firms, the higher the incentive to abate. However, while in the first case, either both types of firms coexist or all firms switch to be green, in the other case, there exists a minimum the number of firms below which all firms remain polluting.

1. Introduction

Environmental protection is arguably one of the most debated political issues of our times. Over the last decades, the increasing number of scientific studies assessing the gravity of the situation of our planet and the growing awareness about the environmental damages caused by pollution raised large political support for a more environmentally friendly economy and strict environmental regulations. Nevertheless, despite the commitments of many governments and the signature of several international agreements, progress on environmental regulation has fallen far short of expectations, and instead, in many areas, the trend seems to be for regulation to be relaxed rather than restricted.

There are several reasons why it is difficult to persuade politicians to approve environmental regulations. The first one is their alleged negative effect on the competitiveness of firms. Indeed, despite the lack of any compelling supporting evidence (Jaffe et al., 1995; Dechezleprêtre and Sato, 2017), it is conventional wisdom among many politicians that higher regulations reduce the competitiveness of firms, leading to offshoring and job losses. A second reason is the increasing political polarisation of the debate about environmental protection in almost every developed country (Dunlap et al., 2016; McCright et al., 2016). This left-right division has resulted in a progressive shift of the respective political platforms, with the consequence of diminishing the possibility of approval of new regulatory policies.

This paper investigates this issue from a different perspective. In fact, we focus on the effects of lobbying carried out by the industries that would be affected by stricter regulations, given that such activity has significantly intensified over the past 20 years.

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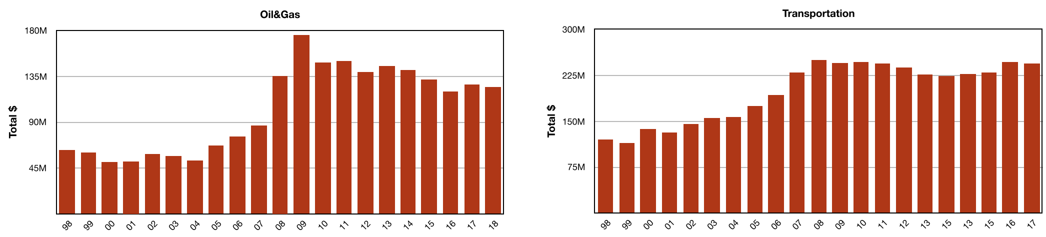
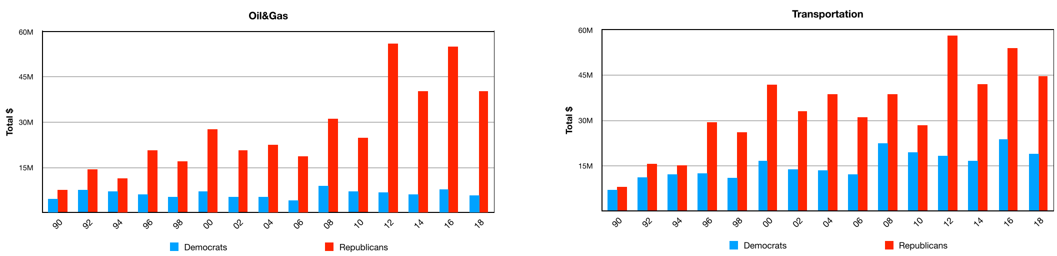


(a) Oil&Gas (b) Transport

Fig. 1. Total lobbying 1998–2018 in the US. (a) Oil&Gas sector, (b) transport sector.



(a) Oil&Gas (b) Transportation

Fig. 2. Campaign contribution: Party split in election years, 1990–2018.

Consider for example the expenditure in lobbying made in the U.S. by firms belonging to the Oil&Gas and Transport sectors, two of the industries most affected by environmental regulations.[1] Fig. 1 reports the total amount of money spent in lobbying by these two interest groups in the period 1998–2018.

It is clear from the figure that the expenditure in lobbying of both industrial groups is significantly higher in the second decade than in the first one. It is worth to notice that the major event that occurred between these two decades was the election of President Obama whose political program included vigorous measures to fight climate change. In particular, the transport sector spent more than $240 million annually during President Obama's first term of office, while from 2007 to 2009, the Oil&Gas sector doubled its spending. Nevertheless, aggregate expenditure, however impressive it may be, does not make it possible to isolate the political preference of these groups. Therefore, Fig. 2 shows the electoral contributions made by these two groups to the Democratic Party and the Republican Party for each election year in the period 1990–2018.

The situation emerging from the figures shows how these two industrial sectors have greatly increased their spending in financing electoral campaigns over time, and in both cases with a clear preference for the Republican party, traditionally opposed to environmental regulation. The phenomenon is particularly evident in the years of presidential election, 2012 and 2016, and the midterm election of 2014 in which the GOP regained the control of the House of Representatives and obtained the majority of the Senate. Brulle (2018) investigates the amount of lobbying spending in influencing climate legislation and provides further evidence that the vast majority of climate lobbying expenditure comes from the sectors majorly affected by regulation (transportation, utility and fossil fuels sectors). In addition, he also finds that the expenditure of the renewable energy sector and environmental organisations is about one tenth of the contribution by fossil fuel actors.[2]

The first aim of this paper is to study how much the possibility for polluting firms to rely on lobbying is effective in preventing the implementation of environmental regulation by the government. Moreover, since the effectiveness of lobbying can be influenced by the degree of market competition (Hillman et al., 2001; Bombardini and Trebbi, 2012), a second objective is to analyse how the incentive for a single company to participate in the lobby varies according to the number of firms active in the market.

To answer these questions, we develop an oligopoly model where the government can impose a tax to induce firms to internalise environmental damage caused by their production process, and firms can fight this policy through lobbying. The main novelty of our contribution is to explicitly take into account the individual choice of each company between internalisation of externality and the participation to the lobbying against taxation. In particular, we consider a four-stage game. In the first stage, each firm chooses

[1] Data and reports are provided by The Center for Responsive Politics, a nonprofit, non-partisan research center based in Washington D.C., that tracks money spent on lobbying and campaign contributions in the U.S. political system (Center for Responsive Politics, 2020).

[2] It is more difficult to find reliable data for Europe, given that the EU Transparency Register relies on voluntary self-reporting and there is no systematic check on data accuracy. Therefore, the risk of under-declarations of lobby spending is high. However, according to the Corporate Europe Observatory (CEO), a research and campaign group active in increasing public awareness of the lobbying activity at the EU level, since 2010 the top five oil and gas corporations and their fossil fuel lobby groups have spent at least a quarter of a billion Euro buying influence at the heart of European decision-making (Corporate Europe Observatory, 2019).

whether to internalise the environmental damage or to join a polluting lobby. In the second stage, the polluting lobby pays the political contribution while in the third stage the government, given its policy objective and the contribution, decides the tax level. Finally, in the last stage of the game firms compete in a Cournot oligopoly.

We analyse two policy objectives. In the first case, which we refer to as the Pigouvian motive, the government wants to minimise the environmental externality. This case provides the strongest case in favour of environmental regulation in line with the aims of the Paris Agreement. In the second case, the government takes also into consideration the consumers' surplus. It could be observed that this government's behaviour is misbehaved since it does not aim to fully internalise the externality. However, this political objective can also be considered as a common goal sought by real regulators. We show that with this consumers' standard motive, the government is more vulnerable to lobby activities since the cost advantage of polluting firms results in higher equilibrium quantities and higher consumers' surplus.

For each case, we firstly define a benchmark tax rate, as the one set up by the government when lobbying is absent. Then, comparing with the benchmark, we study the tax rate as obtained in the lobbying game. Finally, we provide a characterisation of the equilibrium share of firms that decide to switch to be green, depending on the number of firms.

The main result of the paper is that, regardless of the policy objective, a positive share of polluting firms is always present in the market, as long as the number of firms is not too large. Yet, Pigouvian and consumers' standard motives differ significantly in terms of possible equilibria. Indeed, in the first case, a share of green firms is always active regardless of the number of firms. In the second one, if competition is too weak, the outcome is a situation where no firms switches to green. Thus, our results suggest that concentrated oligopolies could be a significant barrier to the implementation of effective environmental policies.

The paper is organised as follows: after the survey of the related literature in section 2, section 3 presents the model in its general setup. Section 4 analyses the common, final stage of the game, while sections 5 and 6 solve the game in two different specifications. Finally section 7 concludes the paper.

2. Related literature

This paper connects two vast strands of literature. The first one is the literature on lobbying, and in particular, the branch originated by the seminal work by Grossman and Helpman (1994). In this framework, lobbying interaction between interest groups and government is modelled as a common agency problem analysed through the use of the menu auction approach (Bernheim and Whinston, 1986).[3] In particular, our paper is closely related to those studies which use this framework to analyse the environmental regulation in small open competitive economies. For example, Fredriksson (1997) studies how the choice of a pollution tax is affected by the lobbying activity, showing that, in general, it differs from the Pigouvian value while Aidt (1998) presents a similar framework where the government can tax either polluting inputs or outputs, showing that the environmental adjustment is targeted at the source. Fredriksson and Svensson (2003) enrich the analysis of environmental policy formation by adding political instability to the lobbying game, showing that it has an ambiguous effect on the stringency of the regulation depending on the degree of corruptibility of the government; while Fredriksson and Wollscheid (2008) show, in a similar framework, that both corruptibility and political instability raise the level of investment in abatement technology by a polluting monopolist. Finally, this paper is also related to the extension of Grossman and Helpman (1994) provided by Mitra (1999), and subsequent developments (see e.g., Laussel, 2006; Bombardini, 2008), where the lobby is not taken as given and firms have to decide whether to incur the costs to form it.

Secondly, this paper belongs to the vast literature that studies the environmental regulation of imperfectly competitive markets.[4] Despite the common analytical tool, this literature is very heterogeneous with respect to the topics.[5] A non-exhaustive list of the main topics discussed in this literature includes: a positive analysis of the optimal tax level in case of imperfect competition (Yin, 2003; Antelo and Loureiro, 2009; Fujiwara, 2009); the combination of a Pigouvian taxation with a production subsidy (Gersbach and Requate, 2004; Li et al., 2016); the utilisation of different instruments to correct the externality other than taxation (Requate, 1993; Heyes, 2000; Sartzetakis, 2004; David, 2005).[6] Related strands of literature study the relationship between environmental regulation and emission-reducing R&D (Poyago-Theotoky, 2007; Ouchida and Goto, 2014) and the effects of environmental taxation on the firm's location choice and foreign investments (Rauscher, 1995; Dijkstra et al., 2011; Elliott and Zhou, 2013).

What emerges from this brief review is that, on the one hand, those who are interested in the political economy of environmental regulation usually do not take into account the market power of firms, while, on the other hand, those who take into account the market power usually maintain a social planner approach in the set up of the regulation. One notable exception is Polk et al. (2014), in which the authors study a lobbying game between the government and a monopolist over the level of environmental regulation. Their aim is different though, given that they are interested in the effects of regulation over the location choice of the production plant.

[3] See Grossman and Helpman (2001, 2002) for an exhaustive discussion on this approach.

[4] The first contributions date back to the critiques of the Pigouvian taxation in a monopolistic market by Buchanan (1969) and Barnett (1980). They pointed out that if firms have market power there is a trade-off between the externality reduction and the underproduction of goods, with an ambiguous effect on social welfare.

[5] For a detailed survey of the literature see Requate (2005, 2006).

[6] For an exhaustive list of possible instruments see Goulder and Parry (2008).

3. The model

We consider a sequential game of environmental regulation in an oligopolistic market characterised by n firms, a government and a lobby of polluting firms.

3.1. Firms

We assume that the n firms are symmetric and produce through a polluting technology characterised by a constant marginal cost that, for simplicity, is normalised to zero. At the beginning of the game, each firm has to decide whether or not to adopt an abatement technology that, at a unitary cost c, eliminates pollution. If the firm does not abate emissions, the production cost remains equal to 0, but it has to pay a tax t on each unit produced.[7] Since we are interested in the analysis of cost advantages of polluting firms, we assume that, despite the difference in abatement technology, firms produce a homogeneous good.[8] We label as "green" the firms deciding to abate (indexed by the subscript g) and as "polluting" the ones deciding not to abate (indexed by the subscript p).

Therefore, the market profits that each firm obtains according to its technological choice are the following:

$$\begin{cases} \pi_p = (p - t)q_p, \\ \pi_g = (p - c)q_g. \end{cases} \tag{1}$$

Given their initial individual choice, firms will be divided into two groups: the polluting one, composed by n_p firms, and the green one composed by n_g firms, where $n_p + n_g = n$. To simplify the notation, let α be the share of polluting firms active in the market, such that $\alpha = n_p/n$, with $\alpha \in [0, 1]$.

3.2. Government

The government is in charge of the environmental policy for the market, which consists of the possibility to impose a tax on the firms that do not abate emissions. Let g being the gross unitary damage of the externality as evaluated by the government. Thus, we can define the total environmental externality $E = gQ_p$ which is linear with respect to the total quantity produced by polluting firms Q_p.[9] We assume that the tax revenue $T = tQ_p$ is used to reduce the level of environmental externality produced by polluting firms. Thus, to simplify the exposition, we introduce the net environmental externality D as the difference between E and T:

$$D(t) = (g - t)Q_p(t). \tag{2}$$

In order to discuss an interesting and meaningful case we assume that $g \in [c; \frac{a+cn}{1+n}]$. This interval ensures that the environmental externality is big enough to induce the government to pursue a strong environmental policy, and is small enough to make lobbying a viable strategy.[10]

Given that all the revenues are used to reduce the externality, it follows that g is a natural upper bound for the tax rate since for $t = g$ the net externality is equal to zero. Moreover, in this framework extra-revenues are possible only out of equilibrium. Indeed, at equilibrium, if $t \geq c$ no firm would choose to be polluting and revenues would be zero anyway. As for a lower bound, however, we do not impose any restriction, allowing for the tax rate to be negative. This choice is rather common in the literature (see among others, Requate, 1993; Fujiwara, 2009; Ouchida and Goto, 2014) given that subsidies and incentives for polluting sectors are still large in the real economy (see e.g., Coady et al., 2017, for an analysis of the subsidy to polluting firms in the energetic sector).

Having to set up the tax rate, the government is moved by a mixed motive. On the one hand, it has a policy objective which, at least to a certain degree, includes an environmental concern. On the other hand, however, the government is also inclined to accept political contributions from the lobby group in exchange for a more accommodating environmental policy.

Formally, we assume the objective function of the government (G) to be a simplified version of the standard linear additive form (Grossman and Helpman, 1994) in terms of its "policy objective" (W) and political contributions from the lobby (L).

$$G(t) = W(t) + L. \tag{3}$$

The simplification consist in assigning equal weights to each term of equation (3). The reason is that applying a weight to W, as in the original formulation, complicates the analysis with no significant modifications of the results. This is particularly true if the government cares only about D, because in this case the parameter g would completely overlap weight parameter in equation (3).

Given that the specific choice of the policy goal of the government depends on many factors which are outside the aim of

[7] A more general abatement cost function could also include a fixed term. However, we normalise this fixed part to zero given that, as illustrated in subsection 3.3, a fixed cost F is introduced to run the lobby.

[8] One may argue that consumers' willingness to pay for green products may be relevant in the decision of firms. However, there are several situations in which it is not unrealistic to think that consumers' do not have information about the environmental impacts of production processes and cannot distinguish "green" products.

[9] The assumption of a linear relationship between the polluting quantity produced and the amount of externality, although used in the literature (see e.g., Lambertini and Tampieri, 2015), is rather restrictive. Another common assumption for this relationship is a quadratic form. However, this choice would increase the complexity of the model, and our simulations suggest that the results would be qualitatively analogous.

[10] Indeed, on the one hand, if $g < c$ the government would set up a tax rate too low to oblige firms to switch to green even without lobbying. On the other hand, the condition $g < \frac{a+cn}{1+n}$ ensures the regular behaviour of the optimal tax as obtained in the lobbying game.

this paper, we consider two specifications. In the first case, the policy goal is only pollution abatement (from now on *Pigouvian government*) meaning that:

$$W(t) = -D(t). \tag{4}$$

We believe that this case is worth discussing for several reasons. The first one is that, as the environmental concerns have largely increased in the last ten years, many political parties are prioritising emissions' reduction over other concerns. This is particularly true in light of the sign of the Paris Agreement which set specific objectives in this direction. Moreover, since we want to study the effectiveness of lobbying, it is reasonable to analyse the case with the strongest environmental motive.

In the second case the government adopts the *consumers surplus standard* (Neven and Ršller, 2005), i.e.:

$$W(t) = S(t) - D(t), \tag{5}$$

where $S(t)$ is the consumer surplus. This specific policy objective seems to be rather commonly pursued by real regulators (see for example Markusen et al., 1995; Rauscher, 1995; Polk et al., 2014), therefore it seems the best suited choice for this analysis. On a more general basis, consumer's surplus introduces a trade-off in the choice of the regulation. This is reasonable because the implementation of strict environmental policies often produces, at least in the short term, negative consequences in terms of prices and production. Therefore, in deciding the level of the tax rate, a government looking for re-election would probably seek a balance between short and long terms political consequences.

A third possibility would be to consider the Social Welfare. However, in this set up the government is not a Social Planner but a political actor who needs to convince voters to ensure its reelection. Since, in this partial equilibrium approach, voters correspond to consumers, it seems natural to assume that the government takes into account only those variables that directly affect them, while the business sector needs to buy influence through the lobbying channel. Moreover, including profits creates an additional distributive issue given that the profits of the two groups reacts to taxation in the opposite way. In addition to that, from the technical point of view, the profits of polluting firms already plays a role in determining the tax rate, therefore including profits also directly in equation (3) would further weaken the environmental motive, therefore reinforcing the main argument of the paper.

3.3. The lobby

Firms that choose not to abate emissions constitute a lobby which interacts on their behalf with the government aiming to reduce the environmental regulation.[11] The lobby operates through a political contribution L to the government, which (as in Grossman and Helpman, 1994) is structured as a *contribution schedule*. In other words, the contribution is a map that assigns for every possible level t chosen by the government the associated amount of contribution, generating a situation of *menu auction* where the bidder (the lobby) offers a set of offers for several possible auctions and it is up to the auctioneer (the government) to choose the one to implement (Bernheim and Whinston, 1986).[12] In addition to political contributions, however, forming and operating a lobby present additional costs (for an extensive discussion see Mitra, 1999). Therefore, we assume that the lobby faces also a fixed cost F needed, for example, to hire lobbyists or rent offices (see for example Laussel, 2006).

The aim of the lobby is to maximise the aggregate profits of its members, that in this case coincides with the aggregate market profits of all polluting firms net of total costs; the objective function of the lobby V is, therefore:

$$V(L) = \Pi_p - L - F. \tag{6}$$

Since the lobby is financed by polluting firms, they have to transfer enough money to cover both the political contribution and the fixed cost. Therefore, we define l_p as the transfer of the single member and by assuming that the expenses are equally divided among the members it follows:

$$l_p = \frac{L + F}{\alpha n}. \tag{7}$$

3.4. Time structure

The game is divided in four stages and solved by backward induction. At the beginning of the game, each firm has to decide whether to switch to the green technology or to maintain the baseline technology and join the lobby. In the following stage, the lobby of polluting firms engages the government with its lobbying activity. In the third stage, the regulator sets up the level of enforcement of the environmental regulation, and in the final stage firms compete in an Cournot oligopoly.

The timeline of the game is represented in Fig. 3.

Actually, as for stages 2 and 3 a well-established result in the lobbying literature (Grossman and Helpman, 2001; Polk et al., 2014) allows to combine them in a single stage lobbying game, solved as if the lobby sets up the tax rate t to maximise its objective function.

[11] We concentrate on the case in which only polluting firms can organise a lobby since the magnitude of contribution coming from environmental organisations and renewable energy sectors is about 1:10 (see Brulle, 2018).

[12] In general, the formation and running of a lobby present both a problem of free-riding, given that the lobbying activity is a public good from the point of view of its members (Polk and Schmutzler, 2005), and a problem of coordination since different members may have different objectives. While the second problem is less important because all firms are symmetric, the free-riding problem remains. However we assume, as it is standard in the literature (see for example Aidt, 1998), that for some external reasons polluting firms are able to overcome these problems.

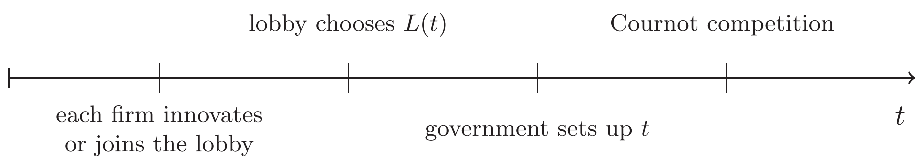


Fig. 3. Timeline.

4. Cournot competition

In the last stage firms, given their choice in terms of technology and the tax rate t, compete in a Cournot oligopoly. For the sake of simplicity we assume demand to be liner and equal to:

$$p = a - Q, \tag{8}$$

where a represents the dimension of the market.

The following Lemma provides the characterisation of the final equilibrium in the market.[13]

Lemma 1. *Let $t \geq c - \frac{a-c}{\alpha n} \equiv \underline{t}$. The equilibrium quantities produced by the single polluting and green firms are respectively:*

$$\begin{aligned} q_p &= \frac{a - t + (1-\alpha)n(c-t)}{1+n}, \\ q_g &= \frac{a - c - \alpha n(c-t)}{1+n}. \end{aligned} \tag{9}$$

The total quantity produced into this market is equal to:

$$Q = \frac{n}{n+1}(a - \alpha t - (1-\alpha)c), \tag{10}$$

and the profits of a single green and polluting firm are equal to:

$$\begin{aligned} \pi_p &= \left(\frac{a - t + (1-\alpha)n(c-t)}{n+1}\right)^2, \\ \pi_g &= \left(\frac{a - c - \alpha n(c-t)}{n+1}\right)^2. \end{aligned} \tag{11}$$

Lemma 1 states that if the tax rate is sufficiently high, the cost advantage of polluting firms is not enough to push green firms out of the market, and the outcome of the market is a Cournot equilibrium where neither the total number of firms present in the market, nor the relative size of the two groups are predetermined.

However, if the tax rate is too low, i.e. if $t < \underline{t}$, the cost advantage of polluting firms is sufficient to push green firms out of the market. Therefore, the final outcome would be a Cournot equilibrium with only αn symmetric polluting firms.

Given these results, it is now convenient to define some additional functions that will be needed in the proceeding of the paper. In particular from equation (9), it is possible to derive by aggregation the total quantities and total profits of each group:

$$\begin{aligned} Q_p &= \alpha n q_p; \qquad & \Pi_p &= \alpha n \pi_p, \\ Q_g &= (1-\alpha) n q_g; \qquad & \Pi_g &= (1-\alpha) n \pi_g. \end{aligned} \tag{12}$$

5. Pigouvian motive

In this section we analyse the game when the government is moved by a Pigouvian motive. Therefore, its policy objective W, as defined by equation (4), is to minimise the level of externality produced by firms.

The first step is to analyse the benchmark case in which there is no lobbying activity, i.e. if $L = 0$. In this case, given equation (3), the government chooses t to maximise its political objective W. Therefore, let t_0 be the tax rate that the government sets up if there is no intervention from the lobby:

$$t_0 = \arg\max_t \; W(t), \tag{13}$$

and let $G_0 = W_0 \equiv W(t_0)$ be the fall back utility for the government. It is straightforward to show that if the government is Pigouvian, it would set the highest possible tax rate, $t_0 = g$, from which it follows $G_0 = 0$.

Therefore, if the lobby wants to obtain a given tax rate $t < t_0$, the minimum required contribution is the one that compensates

[13] All proofs are provided in Appendix A.

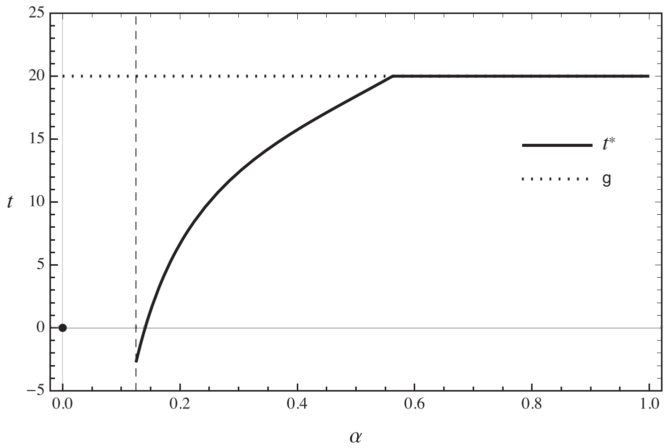


Fig. 4. Optimal tax rate t^*. ($a = 100, c = 16, g = 20, n = 8$).

exactly the government for the loss in utility, *i.e.* the one that guarantees the government $G = G_0$. Thus, for any tax rate $t < t_0$, the generic contribution schedule $L(t)$ is equal to:

$$L(t) = W_0 - W(t), \tag{14}$$

and in this specific case

$$L(t) = D(t). \tag{15}$$

Therefore, given equation (6) it follows that the equilibrium tax rate t^* satisfies the condition:

$$\frac{\partial \Pi_p}{\partial t^*} = \frac{\partial L}{\partial t^*}. \tag{16}$$

The following Lemma characterises the optimal tax as the outcome of the lobbying game between the government and the lobby of polluting firms.

Lemma 2. *Let* $\overline{\alpha} \equiv \frac{1+n}{2n}$, *then:*

(i) *If* $\alpha \leq \overline{\alpha}$, *the equilibrium tax rate is equal to:*

$$t^* = c - \frac{a - g - n(g - c)}{2\alpha n} + \frac{a - c}{2 + 2n(1 - \alpha)}, \tag{17}$$

which is increasing in all parameters and always greater than $\underline{t}$.

(ii) *If* $\alpha > \overline{\alpha}$, *the equilibrium tax rate is equal to g.*

Fig. 4 depicts the optimal tax rate.

The main result of Lemma 2 is twofold. On the one hand, the polluting lobby is able to obtain a more favourable treatment in terms of taxation. On the other hand, however, this ability is not unbounded. Indeed, despite the willingness to reduce the tax rate in exchange for a political contribution, the government increases the taxation the higher the number of polluting firms in the market. Eventually, if the share of polluting firms in the market is too high, the government will set up the highest possible tax rate, $t^* = g$, regardless of the contribution.[14] Finally, it is worth noticing that $\overline{\alpha} > \frac{1}{2}$, i.e. due to lobbying, the government is willing to accept a situation in which the majority of firms remains polluting, the threshold level is also decreasing in n, and it converges to 1/2 when the oligopoly moves toward perfect competition.

Moreover, in general the tax rate may be negative. This would happen for values of α sufficiently low. The intuition is the following: when the share of polluting firms is very small there are two effects. On the one hand, the environmental externality that they cause is almost negligible, while, on the other hand, these firms face a weaker competition in the market given that the vast majority of the firms are green. Both these effects work in favour of the lobby, whose action is therefore very effective. In particular,

[14] As a matter of fact, if $\alpha > \overline{\alpha}$, it follows that $t^* > g$ and $L^* < 0$. In other words, the optimal behaviour of the government would be to set up a tax rate higher than the one needed to ensure no environmental damage and then compensate the lobby with a monetary transfer. This is obviously meaningless, therefore it can be ruled out by assuming that whenever $\alpha > \overline{\alpha}$, the government sets the maximum tax rate without any lobbying activity from the polluting firms.

if profits are large enough, the tax rate can switch to a subsidy. A somewhat related result can be found in Ouchida and Goto (2014) who, even with a different setup, show that a linear tax can turn into a subsidy if emissions are small enough.[15]

A second relevant result is that green firms are always able to stay in the market. This is because on the one hand if the fraction of polluting firms is relatively large, the tax is sufficient to offset their competitive advantage. On the other hand, when the tax becomes a subsidy, the fraction of polluting firms is small enough to maintain the competitiveness of green firms.

In terms of comparative statics, the impact of the number of firms in the market is fairly clear. The higher the number of firms in the market, the lower the profits and the higher the externality. Therefore, the lobby has a smaller possibility to pay a contribution sufficient to influence the policy outcome. The impact of g is also clear. Indeed, the higher the marginal pollution, the higher the motivation of the government toward a strong environmental policy. Therefore, *ceteris paribus*, an increase in g leads to an increase of the "price" that the lobby has to pay for any $t < g$; thus, this increase in price leads to an higher taxation. On the contrary, the impact of a variation of c is less immediate since a variation of c produces two conflicting effects. On the one hand, the higher c the more polluting firms gain by not abating the environmental externality, inducing the lobby to push for an even lower taxation. On the other hand, however, the increase c, by boosting the cost advantage of polluting firms, results in higher production by polluting firms and thus a higher level of externality. The government's reaction would be to increase taxation thus increasing the political contribution required to the lobby to maintain the previous tax rate. As it turns out in Lemma 2, this second effect is stronger than the first one, meaning that the level of externality produced increases at a faster rate than profits, and the final result is that the tax rate is increasing in c.

Finally, in the first stage of the game, each firm has to choose whether to adopt the abatement technology, becoming a green firm, or to join the lobby becoming a polluting one.

Since the aim of the paper is to determine how many firms will choose to innovate and how many will join the lobby and remain polluting, the choice can be treated as a modified version of an entry game where the choice is whether or not to enter the lobby. In the first case, the firm transfers the resources due to the lobby and then obtains the profits of a polluting firm. In the second case, it obtains the fallback profits, that are equal to the profits realised by a green firm. Therefore, the equilibrium fraction of polluting firms will be determined by equating the market profits of a polluting firms net of the transfer to the lobby with the market profits of a green firm:

$$\alpha^* : \ \pi_p - l_p = \pi_g. \tag{18}$$

The following Proposition characterises the condition under which an interior equilibrium exists and is unique:

Proposition 1. *Let* $N \equiv \frac{a-g}{(1-\alpha)(g-c)}$ *and* $\overline{F} \equiv \frac{[a-g-(g-c)(1-\alpha)]^2}{4(1+n)}$, *then:*

(i) *If* $n < N$ *and* $F < \overline{F}$ *there exist a unique* $\alpha^* \in (0,1)$ *such that* $\pi_p - l_p = \pi_g$.
(ii) *Otherwise all firms choose to be green.*

Proposition 1 shows that either the equilibrium is internal or all firms are green. Thus, if the government cares about minimising the externality, the result is twofold. On the one hand, lobbying allows polluting firms to stay in the market by securing a weak enough taxation. On the other hand, however, they are never strong enough to expel green firms from the market. Moreover, we obtain an upper bound for the number of firms beyond which lobbying is no longer a viable strategy, therefore polluting firms have to switch to green. The intuition for this result is that, because of the higher production, tougher competition makes lobbying more costly due to higher externality, while at the same time profits decline. These two effects make lobbying more and more costly as competition increases and more than compensate for the reduction of the fixed cost per firm deriving from the higher number of participants in the lobby. Moreover, the value of $\overline{F}$ is decreasing in n. Hence, when the number of firms increases, an internal solution exists for an smaller interval of the fixed cost. This change in the threshold, together with simulations, suggests that α^* is declining in n.

However, it is not possible to obtain α^* in a closed form. Therefore, to provide a clearer discussion of the economic results we now introduce the simplifying assumption $g = c$. This assumption can be interpreted in two ways: the first one is, of course, a special case in which the marginal damage of emission are equal to the marginal cost of not producing it. The second interpretation is connected to the policy objective of the government. Indeed, given that g measures the marginal pollution as it is evaluated by the government, the equality between marginal damage and marginal cost would mean that the government evaluates the externality as the competitive advantage that polluting firms enjoy by choosing not to abate, which if removed would ensure that all the firms within the industry would switch to green.

Therefore, we firstly compute the optimal tax rate in the simplified case, then we solve the entry game obtaining the equilibrium share of polluting firms, α^*. Thus, given Lemma 2 and assuming $g = c$, it follows that the optimal tax rate is:

$$t^* = c - \frac{a-c}{2\alpha n} \cdot \frac{n+1-2\alpha n}{n+1-\alpha n}. \tag{19}$$

[15] To be precise Ouchida and Goto (2014) consider a model of emission regulation and emission-reducing R&D, (building on Poyago-Theotoky, 2007). Nevertheless, despite the difference in the subject of the analysis between this work and their work, the decision of the government about the tax rate is analogous.

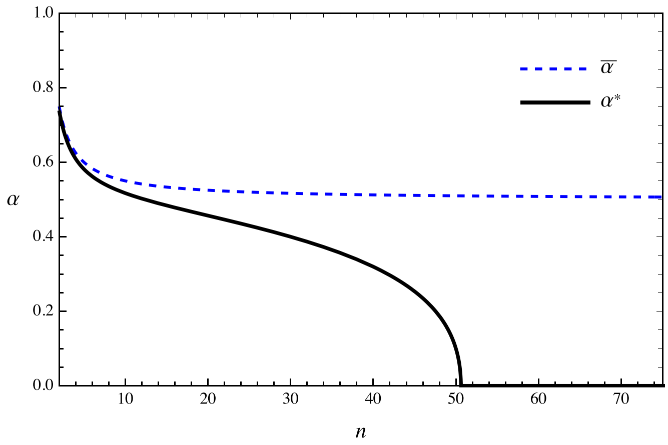


Fig. 5. Equilibrium share of polluting firms α^*. ($a = 100, c = 15, F = 35, n \geq 2$).

Having derived the optimal tax rate, the following Corollary characterises the equilibrium of the game:

Corollary 1. *Let* $\overline{n} \equiv \frac{(a-c)^2}{4F}$, *then:*

(i) *If* $n \leq \overline{n}$

$$\alpha^* = \frac{n+1}{n} - (a-c)\,\frac{a-c-\sqrt{(a-c)^2-4F(n+1)}}{4Fn}, \tag{20}$$

with α^* *decreasing in n and F and always lower that* $\overline{\alpha}$.

(ii) *If* $n > \overline{n}$, *all the firms choose to be green.*

Fig. 5 depicts the result.

Corollary 1, while confirming the results of Proposition 1 provides to additional insights. The first one is about the upper bound of α. Indeed, Lemma 2 states that if $\alpha \geq \frac{1+n}{2n}$, the tax rate is equal to c, and there is no incentive for any other firm to join the lobby, paying its share of setup costs to obtain the same gross profit of a green firm. However, Corollary 1 shows that such threshold is actually never reached, and the share of polluting firms is far lower than such limit. The second one is about the effect of an increase in competition on the choice to join the Lobby. By computing the partial derivative of α^* with respect to n, it is now possible to prove that the share of polluting firms is a decreasing function of the number of firms. Thus confirming, at least for this case, the intuition of Proposition 1. Intuitively, as the number of firms in the market increases, profits decrease while quantity, and increases along with the externality. Therefore the possibility for firms to pay the extra costs related to the lobbying activity decreases. Eventually, profits will no longer be sufficient to cover those costs, and all firms will choose to internalise the environmental externality.

6. Consumer standard motive

This section investigates the case where the government applies the so-called consumers standard, i.e. it takes also into account the consumers' surplus. In this case, the policy objective W, as defined in equation (5), presents an additional trade-off. Indeed, an increase in the tax rate reduces both environmental externality and consumers' surplus, which in a Cournot oligopoly with linear demand and linear cost functions is equal to $S = (a-p)Q/2 = Q^2/2$.

The structure of the game is analogous to the one of section 5, therefore, results that have already been discussed are omitted.

The first step is to evaluate the choice of the government in the benchmark case, i.e, the case in which there is no lobbying activity. In this case the situation is not as clear as it was in the Pigouvian case because the baseline tax may be lower than g. Since we are interested in the misbehaviour of government caused by the lobby, we restrict our analysis to the case in which government without lobbying always chooses the highest tax rate $t_0 = g$.

Lemma 3. *Let* $g < \frac{a+cn(2+n)(1-\alpha)}{1+n(2+n)(1-\alpha)}$, *then, absent any pressure from the polluting lobby, the government sets up the highest possible tax rate.*

Thus, under this regularity condition, $t_0 = g$ and the baseline utility of the government is $G_0 = S_0 \equiv S(g)$. It then follows from equation (14):

$$L(t) = W_0 - W(t) = D(t) - \Delta S. \tag{21}$$

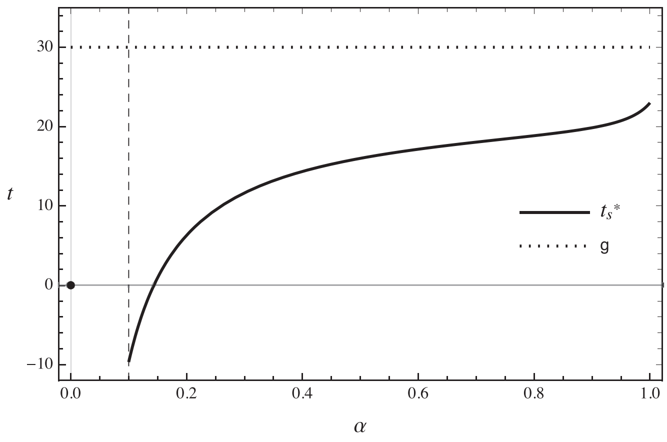


Fig. 6. Optimal tax rate t_s^*. ($a = 100, c = 25, g = 30, n = 10$).

Considering equation (21) the contribution is lower than in equation (15). The reason is that consumers' surplus increases if taxation decreases. Thus, this trade-off reduces the cost of lobbying due to the increase in externality.

This reduction in the required political contribution has a significant impact on the optimal tax rate, as stated by the following proposition.

Lemma 4. *The equilibrium tax rate t_s^* is equal to:*

$$t_s^* = \frac{g(n+1)[1+(1-\alpha)n] - a[1+2(1-\alpha)n] - cn^2(1-\alpha)(1-2\alpha)}{\alpha n[1+2(1-\alpha)n]}, \tag{22}$$

which is increasing in α, g and n; while it is increasing in c if $\alpha > \frac{1}{2}$ but decreasing if $\alpha > \frac{1}{2}$. Moreover, the tax rate t_s^*, is always lower than t^* and never lower than $\underline{t}$.

Fig. 6 depicts the optimal tax rate.

As expected, lobbying is more effective when the government cares about consumers' surplus. Indeed, the tax derived in Lemma 4 is always lower than the one obtained in Lemma 2, this also implies that the optimal tax is always interior. Thus, there is no upper bound to α above which the tax rate returns to its benchmark level g. Nevertheless, except for one case, the tax rate is greater than $\underline{t}$. This means that, in general, the polluting lobby is not strong enough to expel green firms from the market.

The comparative statics with respect of α, g and n is the same of Lemma 2. The tax rate is an increasing function of all these parameters. The situation is different for the partial derivative with respect to c. Indeed, the effect of an increase of c remains positive only if the majority of firms is polluting while if the majority of firms is green, the effect becomes negative. The economic intuition for this switch relies on the effect of the change of c on the surplus. Indeed, if c increases green firms reduce production while polluting firms increase it, causing an increase of the environmental externality. In the Pigouvian case, the government reacts by increasing taxation, leading tough to a further reduction of consumers' surplus. Under consumers' standard, however, the higher production of polluting firms, even if increase the level of externality, compensates the reduction is surplus due to the lower production. This trade-off produces here a peculiar result. Indeed, if the majority of firms is green, the increase in surplus is higher than the increase of externality; however, the inequality reverses when the majority of firms is polluting. Thus, the government increases the tax in the first case, and reduce it in the second one.

Having obtained the optimal taxation, the following proposition characterises the condition under which different equilibria exist.

Proposition 2. *Let $F_{max} \equiv \frac{[a+2an+cn^2-g(n+1)^2]^2}{2(n+1)^2(2n+1)}$; $F_{min} \equiv \frac{(a-g)^2(1+2n)-2n(g-c)^2(1+n)^2}{2(1+n)^2}$ and $g^* \equiv \frac{2an(1+2n)+2c+nc[8+5n(2+n)]}{2+n[10+n(14+5n)]}$. Then, the equilibrium of the entry game is unique and can be either an interior or a corner one. In particular:*

(i) *All firms choose to be green if $F > F_{\max}$.*
(ii) *All firms choose to be polluting if either*
  (a) *$F \in [0; F_{\max}]$ and $g \le g^*$ or,*
  (b) *$F \in [0; F_{\min}]$ and $g > g^*$.*
(iii) *There exists a unique $\alpha^* \in (0,1)$ if $F \in (F_{\min}; F_{\max})$ and $g > g^*$.*

The result of Proposition 2 is represented in Fig. 7. The red curve represents $F_{\max}$, while the blue curve represents $F_{\min}$. Therefore, the white area above the red curve corresponds to the corner solution $\alpha^* = 0$. The light blue area which lies below both curves corresponds to the corner solution $\alpha^* = 1$. Finally, the light orange correspond to the area where there exists an interior solution $\alpha^* \in (0,1)$.

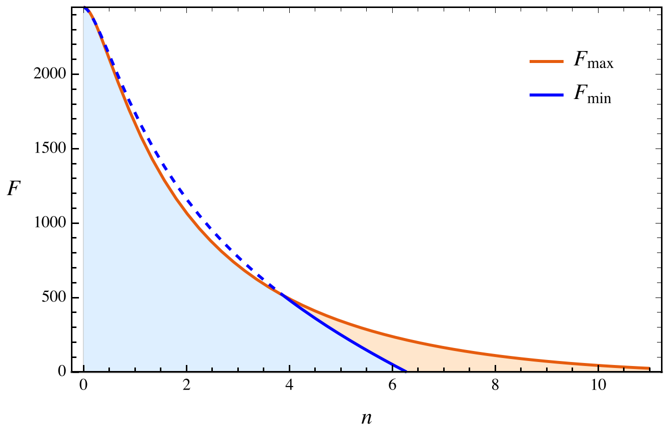


Fig. 7. Existence and uniqueness of the solution. ($a = 100, c = 20, g = 30$).

The main result of Proposition 2, which is also the main differences with respect to Proposition 1, is the existence of three different kinds of equilibria. In particular, differently to Proposition 1 it is also possible to have equilibria in which all firms decide to remain polluting. Moreover, the interior equilibrium exists only if government's environmental motivation is strong enough. If that is not case, the only equilibria are the extremes in which all firms decide to be either polluting or green.

It is worth noticing that, likewise Proposition 1, both $F_{\max}$ and $F_{\min}$ are decreasing in n. Therefore, as the number of firms increases the only equilibrium left is the corner $\alpha = 0$ in which all firms choose to be green.

However, neither in this scenario it is not possible to obtain a solution in a closed form; therefore we again analyse the simplified situation in which $g = c$. In this case, tough, simplification results in a worst case scenario for the environmental policy; nevertheless it allows us to clarify the impact of the number of firms over the realised equilibrium.

If $g = c$ the equilibrium tax rate t^* is equal to:

$$t_s^* = c - \frac{a-c}{\alpha n}, \tag{23}$$

such that only polluting firms remains in the market. Therefore, in this case the action of the polluting lobby is very effective. Indeed, the government moves from the maximum tax rate to the rate that pushes the green firms out of the market and even if the tax rate increases when the share of polluting firms in the market does so, it never reaches the maximum level c.

As one may expect, in this case the extremely favourable outcome for polluting firms in terms of taxation produces a clear cut result.

Corollary 2. *Let* $\overline{n}_s \equiv \frac{(a-c)^2}{4F}$, *then:*

(i) *If* $n \leq \overline{n}_s$, *all firms choose to be polluting*
(ii) *If* $n > \overline{n}_s$, *all firms choose to be green.*

Thus, the simplification $g = c$ produces only corner equilibria depending on the number of firms. If the competition is to weak, all firms choose not to innovate and the other way around if the number of firms is large enough. Finally, as expected, the threshold $\overline{n}_s$ is a decreasing function of F, therefore as the set-up cost increases, the critical number of firms above which lobbying is not anymore viable decreases.

7. Final remarks

In this paper, we investigate how firms react to an environmental regulation when they have the choice between fully complying or lobbying the government to obtain a looser regulation. More precisely, our major contribution is to explicitly take into account the impact of market competition on both the lobbying game and firms' individual choice. We study two scenarios with respect to the government's policy objective: the first one in which the government has a pure Pigouvian motive, and the second in which it also cares about consumers surplus. The first case corresponds to a government in line with the spirit of the Paris Agreement, while the second objective is a typical standard for real regulators where government has to balance two different benefits: the reduction of the environmental damage and the consumer surplus.

Our results highlight how, in general, greater market competition weakens the action of the polluting lobby, and increase firms' incentive to become green rather than relying on lobbying. In particular, in both scenarios when the number of firms is large enough, all firms switch to be green. However, the two cases present a relevant difference when competition is weak. As a matter of fact, under the Pigouvian motive, a positive share of green firms is always present, regardless of the strength of competition. On the contrary, under consumers' standard, as long as the number of firms is small enough, all firms choose to remain polluting. In other words, when the government in determining the environmental regulation takes into consideration other economic objectives, *ceteris paribus*, it becomes more vulnerable to lobbying activities. As a result, the strength of regulation and the reduction of the externality are significantly lower than in the Pigouvian case. This effect is stronger the lower the number of firms in the market.

Finally, we believe that this framework leaves space for extension and further research. Indeed, there are several issues which undoubtedly play a relevant role in the implementation of environmental regulation and on the effectiveness of lobbying activity that have been left aside. First of all, we chose the simplest way to model market competition, especially concerning the homogeneity of goods. Whilst there are many real situations in which homogeneity among green and polluting products is a reasonable assumption, it is undeniable that there is an increasing preference among consumers for "green products". Taking into account this preference could influence the result in a meaningful way by creating a market incentive for the adoption of green technology. A second promising extension concerns the study of firms' entry in the market; in particular, future research could include the possibility for already active polluting firms to prevent the entry of new green competitors. Intuitively, the high effectiveness of lobbying in a small oligopoly would provide an additional incentive for such a deterrent action, reinforcing the negative result for environmental regulation. Finally, in this paper, we simplified the lobbying interaction by ruling out the possibility of free-riding among polluting firms. While in real economies the large existence of lobbies suggests that such free-riding issue is not that compelling, its inclusion in the analysis would strengthen the framework, possibly providing a robustness check for our results.

Acknowledgements

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Appendices

A Proofs

Proof of Lemma 1. The first step of the Proof is to derive the Cournot equilibrium for the entire market.

Given equation (8), the quantity produced by firm i in a Cournot oligopoly with n firms is equal to:

$$q_i^n = \frac{a - c_i}{(n+1)} + \frac{n(\bar{c} - c_i)}{(n+1)}, \tag{A.1}$$

where $\bar{c}$ is the average marginal cost.

At this stage of the game the n firms are divided into two groups: the green ones, and the polluting ones; define n_g and n_p the number of firms of each type.

It then follows that the average marginal cost is equal to

$$\bar{c} = \frac{n_p t + n_g c}{n}, \tag{A.2}$$

which can be written as:

$$\bar{c} = \alpha t + (1 - \alpha)c. \tag{A.3}$$

by substituting equation (A.3) in equation (A.1) equation (9) can be derived.

$$q_p = \frac{a - t + (1-\alpha)n(c - t)}{1 + n}, \qquad q_g = \frac{a - c - \alpha n(c - t)}{1 + n}. \tag{A.4}$$

In order to derive equation (A.9), first notice that by (10) it follows that

$$p = \frac{a + n(\alpha t + (1-\alpha)c)}{(1+n)}, \tag{A.5}$$

given the equation of price, equation (A.9) follows immediately.

The second step of the Proof is to analyse the corner solution that originates if the cost advantage of the polluting firms is too high. Green firms stay in the market only if they have the incentive to produce a non-negative quantity, i.e. only if $q_g \geq 0$, which implies

$$t \geq c - \frac{a - c}{\alpha n} \equiv \underline{t}. \tag{A.6}$$

Therefore if $t < \underline{t}$, green firms prefer not to produce, then the market will be composed only by the αn polluting firms.

$$q_p = \frac{a - t}{\alpha n + 1}. \tag{A.7}$$

The total quantity produced in this market is equal to:

$$Q = \frac{\alpha n}{\alpha n + 1}(a - t). \tag{A.8}$$

and the profits of a single polluting firm are equal to:

$$\pi_p = \left(\frac{a-t}{\alpha n+1}\right)^2. \tag{A.9}$$

Proof of Lemma 2. Firstly, given equations (2) and (15) it follows that:

$$L = (g-t)Q_p. \tag{A.10}$$

Therefore the optimal tax rate t^* of equation (17) is obtained by substituting equation (A.10) into the FOC, of equation (16).

The corner solution follows directly from the constraint $t^* \le g$, which, under the regularity condition $g \le \frac{a+cn}{1+n}$, is verified as long as

$$\alpha \le \frac{1+n}{2n} \equiv \overline{\alpha}, \tag{A.11}$$

while if $\alpha > \overline{\alpha}$, the consequence would be that $t^* > g$ and $L^* < 0$.

The partial derivatives with respect to g is equal to:

$$\frac{\partial t^*}{\partial g} = \frac{1+n}{2\alpha n}, \tag{A.12}$$

which is clearly always positive;

The partial derivative of t^* with respect to is c is equal to:

$$\frac{\partial t^*}{\partial c} = 1 - \frac{1}{2\alpha} - \frac{1}{2+2n(1-\alpha)}, \tag{A.13}$$

which is positive as long as $\alpha < \overline{\alpha}$.

Finally, the partial derivatives with respect to α and n take the following forms respectively:

$$\frac{\partial t^*}{\partial \alpha} = \frac{a-g-n(g-c)}{2n\alpha^2} + \frac{2n(a-c)}{(2+2n-2\alpha n)^2}, \tag{A.14}$$

and

$$\frac{\partial t^*}{\partial n} = \frac{1}{2}\left[\frac{a-g}{\alpha n^2} - \frac{(a-c)(1-\alpha)}{(1+n-\alpha n)^2}\right], \tag{A.15}$$

which are both positive under the assumption $g \le \frac{a+cn}{1+n}$.

Finally, we are left to prove that green firms are always able to remain in the market. Recalling that by Lemma 1, green firms stay in the market as long as $t \ge \underline{t}$, it follows:

$$c - \frac{a-g-n(g-c)}{2\alpha n} + \frac{a-c}{2+2n-2\alpha n} > c - \frac{a-c}{\alpha n}; \tag{A.16}$$

this condition can be rewritten as

$$\frac{a-c}{2+2n-2\alpha n} > \frac{a-g-n(g-c)}{2\alpha n} - \frac{a-c}{\alpha n}. \tag{A.17}$$

The LHS of this inequality is always positive, whereas the RHS can be written as

$$-\frac{a+(g-c)(1+n)}{2\alpha n}, \tag{A.18}$$

which is always negative.

Proof of Proposition 1. We need to prove that the equation

$$\pi_p(\alpha) - l_p(\alpha) = \pi_g(\alpha), \tag{A.19}$$

in the space $\alpha \in (0,1)$ admits a solution and that such solution is unique. First of all we will define as $f_1(\alpha)$ the left-hand side and by $f_2(\alpha)$ the right-hand side of the equation. By substituting the optimal taxation in the equation and after some simplifications we obtain the following functions:

$$f_1(\alpha) = \frac{[a-g-(g-c)(1-\alpha)n]^2 - 4F(1+(1-\alpha)n}{\alpha n},$$
$$f_2(\alpha) = \frac{[a-c+(g-c)(1+(1-\alpha)n]^2}{1+n(1-\alpha)}, \tag{A.20}$$

which are both continuous for $\alpha \in (0,1)$.

From the equation of f_1 we can derive the upper bound N for the number of firms, in fact the term

$$a-g-(g-c)(1-\alpha)n, \tag{A.21}$$

correspond to the quantity produced by a single polluting firm, the upper bound is derived by imposing the non negativity of q_p.

The second step is to evaluate both functions at the extremes of the segment.

If $\alpha = 0$, it follows, as long as $F < \overline{F}$[16]

$$\begin{aligned} f_1(0) &= \lim_{\alpha \to 0^+} \frac{[a-g-(g-c)n]^2 - 4F(1+n)}{\alpha n} = +\infty, \\ f_2(0) &= \frac{[a-c+(g-c)(1+n]^2}{1+n}, \end{aligned} \tag{A.22}$$

and trivially holds that $f_1(0) > f_2(0)$.

If $\alpha = 1$, it follows:

$$\begin{aligned} f_1(1) &= \frac{(a-g)^2 - 4F}{n}, \\ f_2(1) &= (a-2c+g)^2, \end{aligned} \tag{A.23}$$

with $f_1(1) < f_2(1)$. Indeed, we can firstly notice that, given $g \geq c$ it follows:

$$a - 2c + g \geq a - 2g + g = a - g, \tag{A.24}$$

then it is trivial to recognise that

$$\frac{(a-g)^2 - 4F}{n} < (a-g)^2 \leq (a-2c+g)^2. \tag{A.25}$$

Being $f_1(0) > f_2(0)$ and $f_1(1) < f_2(1)$, there exists at least one solution.

The uniqueness of the solution is guaranteed by the convexity of f_1 and the strict increasing monotonicity of f_2. Indeed:

$$\frac{\partial^2 f_1}{\partial \alpha^2} = \frac{(a-n(g-c)-g)^2 - 4F(n+1)}{\alpha^3 n}, \tag{A.26}$$

is always positive in the allowed space of parameters, while

$$\frac{\partial f_2}{\partial \alpha} = \frac{n(a-c)^2}{(1+n-\alpha n)^2} - n(c-g)^2, \tag{A.27}$$

is always positive, as long as $n < N$.

Proof of Corollary 1. Given equation (19), it follows that

$$\pi_p = \frac{(a-c)^2}{4\alpha^2 n^2}, \tag{A.28}$$

while

$$\pi_g = \frac{(a-c)^2}{4(1+n-\alpha n)^2}. \tag{A.29}$$

Moreover, given that

$$L = (a-c)^2 \frac{1+n(1-2\alpha)}{4\alpha n(1+n-\alpha n)}, \tag{A.30}$$

it follows that the equilibrium condition stated in equation (18) can be rewritten as:

$$(a-c)^2 \frac{1-n(1-2\alpha)}{4\alpha n(1+n-\alpha n)^2} = \frac{F}{\alpha n}, \tag{A.31}$$

and solving for α gives equation (20).

However, one can immediately recognise that such optimal value α^* exists as long as the argument of the square root is non-negative. This implies that $(a-c)^2 - 4F(n+1) \geq 0$, from which it follows

$$n \leq \frac{(a-c)^2}{4F} - 1 \equiv \overline{n}. \tag{A.32}$$

If $n > \overline{n}$, the profit that a firm obtains by choosing not to innovate is always lower than the profit obtained by the one choosing to innovate, therefore all firms choose to be green.

The partial derivative with respect to the number of firms takes the following form

$$\frac{\partial \alpha^*}{\partial n} = \frac{(a-c)^2 - 4F}{4Fn^2} - \frac{(a-c)}{4Fn^2} \cdot \frac{(a-c)^2 - 2F(n+2)}{\sqrt{(a-c)^2 - 4F(n+1)}}, \tag{A.33}$$

[16] If the condition is not fulfilled, the limit is equal to $-\infty$.

which in the space of parameters such that α^* exists is always negative.

Finally, the inequality $\alpha^* < \overline{\alpha}$ implies

$$\frac{(a-c)^2 - 2F(n+1) - (a-c)\sqrt{(a-c)^2 - 4F(n+1)} +}{4Fn} > 0, \tag{A.34}$$

which under the condition $n < \overline{n}$, is always true.

Proof of Lemma 3. The benchmark case corresponds to the one in which $L = 0$. This case then corresponds to the case in which the government maximises

$$G(t) = S(t) - D(t), \tag{A.35}$$

that is a concave function.

Therefore from the FOC, it follows that the optimal tax rate is equal to

$$t_0 = \frac{a + cn(n+2)(1-\alpha) + g(1+n)(1+(1-\alpha)n)}{2(n+1)^2 - \alpha n(2n+3)}, \tag{A.36}$$

and by imposing $t_0 < g$ we obtain the condition

$$g > \frac{a + cn(n+2)(1-\alpha)}{1 + n(n+2)(1-\alpha)}. \tag{A.37}$$

Proof of Lemma 4. Firstly, given equations (2) and (21) it follows that:

$$L(t) = (g-t)Q_p - \frac{Q^2 - Q_0^2}{2}, \tag{A.38}$$

where Q_0 represents the total quantity produced in the benchmark case. Therefore the optimal tax rate t^* is obtained by substituting equation (A.38) into the FOC, of equation (16).

Firstly, by imposing $t_s^* < g$ we obtain, after some manipulations, the following condition:

$$g(1 + (1-\alpha)n(n+2-2\alpha n)) > a(1 + 2(1-\alpha)n) + (1-\alpha)(1-2\alpha)cn^2, \tag{A.39}$$

which is never fulfilled in the parameter set.

Secondly by imposing $t_s^* > \underline{t}$ we obtain the condition

$$\frac{(n+1)(g-c)(1+(1-\alpha)n)}{\alpha n(1+2(1-\alpha)n)} > 0, \tag{A.40}$$

which is always true.

Finally by comparing the tax rate under different objective functions we obtain that $t_s^* < t^*$ if:

$$-(n+1)\frac{(a-g+(2a-c-g)(1-\alpha)n)}{2\alpha n(1+(1-\alpha)n)(1+2n(1-\alpha))} < 0, \tag{A.41}$$

which is always verified.

The partial derivatives of t^* with respect to α g and n are respectively:

$$\frac{\partial t^*}{\partial \alpha} = \frac{a(1+2(1-\alpha)n)^2 + cn^2\left(1+2n(1-\alpha)^2 - 2\alpha^2\right)}{n(\alpha+2(1-\alpha)\alpha n)^2} - \frac{g(n+1)\left(1+n\left(3-4\alpha+2(1-\alpha)^2 n\right)\right)}{n(\alpha+2(1-\alpha)\alpha n)^2}, \tag{A.42}$$

$$\frac{\partial t_s^*}{\partial g} = \frac{(n+1)(1+(1-\alpha)n)}{\alpha n(1+2(1-\alpha)n)}, \tag{A.43}$$

and

$$\frac{\partial t_s^*}{\partial n} = \frac{a(1+2(1-\alpha)n)^2 - (1-\alpha)n[n(g(3-2\alpha) - c(2\alpha-1) + 4g] - g}{\alpha n^2(1+2(1-\alpha)n)^2}, \tag{A.44}$$

which are all positive.

As for the partial derivative of t_s^* with respect to c, it takes the following form,

$$\frac{\partial t_s^*}{\partial c} = \frac{(1-\alpha)(2\alpha-1)n}{\alpha(1+2(1-\alpha)n)}, \tag{A.45}$$

and we can notice that it positive for $\alpha > \frac{1}{2}$ and otherwise negative.

Proof of Proposition 2. Given equation (22), it follows that

$$\pi_p = \left(\frac{a(1+2n(1-\alpha)) + cn^2(1-\alpha)^2 - g(1+n-\alpha n)^2}{\alpha n(1+2n(1-\alpha))}\right)^2, \tag{A.46}$$

while

$$\pi_g = \frac{(g-c)^2(1+n-\alpha n)^2}{(1+2(1-\alpha)n)^2}, \tag{A.47}$$

Let us define the function $\Delta\pi$ in the following way:

$$\Delta\pi(\alpha) = (\pi_p(t_s^*) - l_p(t_s^*)) - \pi_g(t_s^*), \tag{A.48}$$

which is continuous in the open interval $(0, 1)$.

As a first step we is to compute the value in the extremes of the segment $[0, 1]$: by computing the limit for $\alpha \to 0^+$ we can derive the first condition over F. Indeed we obtain that

$$\lim_{\alpha\to 0^+} \Delta\pi(\alpha) = +\infty \iff F < \frac{\left(a(1+2n) + cn^2 - g(n+1)^2\right)^2}{2(n+1)^2(2n+1)} \equiv F_{max}, \tag{A.49}$$

therefore, if $F > F_{\max}$ the limit is equal to $-\infty$, and no firm would choose to enter into the lobby.

The second step is to compute the value of $\Delta\pi(\alpha)$ for $\alpha = 1$:

$$\Delta\pi(1) = \frac{(a-g)^2(2n+1) - 2F\left(n^2+2n+1\right)}{2n(n+1)^2} - (g-c)^2. \tag{A.50}$$

It can be noticed that $\Delta\pi(1)$ can be either positive or negative, indeed:

$$\Delta\pi(1) > 0 \iff F < (a-g)^2\frac{(2n+1)}{2(n+1)^2} - n(c-g)^2 \equiv F_{min}. \tag{A.51}$$

The third step it to verify that $\Delta\pi(\alpha)$ is strictly monotonically decreasing in $\alpha \in (0, 1)$. As a matter of fact it can be verified that:

$$\frac{\partial\Delta\pi}{\partial\alpha} < 0 \text{ aslongas } F < F_{max} \tag{A.52}$$

Therefore in the space of the parameters in which the problem is meaningful, the function $\Delta\pi$ is strictly monotonically decreasing. It follows that, on the one hand, if $F < F_{\min}$, $\Delta\pi > 0$ for any value of α, which implies that all firms will remain polluting and enter the lobby. On the other hand, if $F < F_{\min}$, $\Delta\pi(1) < 0$, therefore there exists a unique α^* such that $\Delta\pi = 0$.

However, it is not always the case that $F_{\max}$ is greater than $F_{\min}$ neither the other way round. Indeed, we can notice that

$$F_{max} > F_{min} \iff g > \frac{2an(1+2n) + c(2+n(8+5n(2+n)))}{2+n(10+n(14+5n))} \equiv g^*. \tag{A.53}$$

Therefore, if $g < g^*$, it follows that either $F < F_{\max} < F_{\min}$ implying $\alpha^* = 1$, or $F > F_{\max}$ implying $\alpha^* = 0$ while no interior solution exists. Thus $g > g^*$ is a necessary condition for an interior solution.

As a final step we provide the partial derivatives of the thresholds $F_{\max}$ and $F_{\min}$ with respect to n:

$$\frac{\partial F_{max}}{\partial n} = -\frac{n\left(a(2n+1) + cn^2 - g(n+1)^2\right)}{(n+1)^3(2n+1)^2} \cdot \cdot \frac{\left(a(2n+1) + cn^2 - g(n+1)^2 + 2(n+1)^2(g-c)\right)}{(n+1)^3(2n+1)^2} \tag{A.54}$$

which is negative in the allowed space of parameters,

$$\frac{\partial F_{min}}{\partial n} = -\frac{n(a-g)^2}{(n+1)^3} - (g-c)^2 \tag{A.55}$$

which is clearly always negative.

Proof of Corollary 2. Given equation (22), it follows that

$$\pi_p = \left(\frac{a-c}{\alpha n}\right)^2, \tag{A.56}$$

while $\pi_g = 0$. It follows that the net profits of a polluting firm are equal to:

$$\pi_p - l_p = (a-c)^2\frac{(2n+1)}{2\alpha n(n+1)^2} - \frac{F}{\alpha n}, \tag{A.57}$$

while obviously $\pi_g = 0$.

It follows that the equilibrium condition stated in equation (18) can be rewritten as:

$$\frac{(a-c)^2(2n+1)}{2\alpha n(n+1)^2} = \frac{F}{\alpha n}, \tag{A.58}$$

and it is immediate to verify that there is no α^* satisfying this condition. In fact, either $\pi_p > l_p$ for every α or the other way around.[17]

Condition $\pi_p > l_p$ holds if

$$n \leq \frac{(a-c)\left(\sqrt{(a-c)^2-2F}+a-c\right)}{2F} - 1 \equiv \overline{n}_s, \tag{A.59}$$

If it is the case, then it is always convenient to be polluting rather than green, therefore all firms will take this decision and $\alpha^* = 1$.

On the other hand, if $n > \overline{n}$ the inequality holds in the opposite direction, $\pi_p < l_p$, therefore all firms choose the innovate and $\alpha^* = 0$.

Finally, let us compute the partial derivative of the threshold $\overline{n}$ with respect to the set up cost F:

$$\frac{\partial \overline{n}_s}{\partial F} = -\frac{(a-c)(a-c+\sqrt{(a-c)^2-2F})}{2F^2} - \frac{(a-c)}{2F\sqrt{(a-c)^2-2F}} \tag{A.60}$$

which is clearly always negative in the allowed space of parameters.

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[17] Actually for $n = \overline{n}$ it follows that $\pi_p = l_p$ for every α. In this case we assume that firms prefer to be polluting.